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A Pilot Study to Estimate Abundance of the U.S. Atlantic Coastal Migratory Bottlenose Dolphin

by

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A Pilot Study to Estimate Abundance of the U.S. Atlantic Coastal Migratory Bottlenose Dolphin [1]

By Robert A. Blaylock

Abstract: *Two types of aerial surveys were conducted along the U.S. Atlantic coast during the summer in 1994 to estimate abundance of the coastal migratory Atlantic bottlenose dolphin. One survey type was a count of dolphins within approximately one km of shore; the other was a line transect survey with transects placed randomly. The highest count of three alongshore counts in the area from New Jersey to mid-Florida was 2,482 dolphins, but this could not be extrapolated to the range of the coastal stock, which is believed to extend to the 25 m isobath, because of the sampling design. The coefficient of variation (cv) of the mean of three alongshore counts in the area between Sandy Hook, NJ and Cape Hatteras, NC was 0.74 and required approximately 70 flight hours to complete. Approximately 980 flight hours in the same area would be required to achieve a cv = 0.20 using this design. It required 30 flight hours to complete a line transect sampling survey in the same area with a cv = 0.40 and, thus, would require approximately 120 flight hours to achieve an acceptable level of precision using this method. The line transect survey provided information to allow calculation of survey design parameters for estimating dolphin abundance throughout the region with acceptable precision.*

INTRODUCTION

The coastal Atlantic bottlenose dolphin, *Tursiops truncatus*, stock in the U.S. is believed to inhabit the nearshore coastal waters north of Cape Hatteras from the nearshore surf zone out to the 25 m isobath during the summer (Mead 1975, Kenney 1990); however the stock structure is uncertain. Scott et al. (1988) hypothesized a single coastal migratory stock ranging seasonally from as far north as Long Island, NY, to as far south as central Florida, citing stranding patterns during a high mortality event in 1987-88 and observed density patterns along the U.S. Atlantic coast. It has been suggested that the coastal stock is restricted to waters < 25 m in depth within the northern portion of its range (Kenney 1990) because of an apparent disjunct distribution of bottlenose dolphins centered on the 25 m isobath which was observed during surveys of the region (CeTAP 1982). The lowest density of bottlenose dolphins was observed over the continental shelf, with higher densities along the coast and near the continental shelf edge.

The coastal stock is believed to reside south of Cape Hatteras in the late winter (Mead 1975; Kenney 1990); however, the depth distribution of the stock south of Cape Hatteras is not known. Mitchell (1975) estimated that the population, which was exploited by a shore-based net fishery until 1925 (Mead 1975), was at least 13,748 in the 1800s. Kenney (1990) reported that, based on aerial surveys conducted by the University of Rhode Island in 1978-1982 (CeTAP 1982), the inshore stock of bottlenose dolphins in the area north of Cape Hatteras was estimated to be less than 1,000 dolphins.

A working hypothesis for the coastal bottlenose dolphin stock structure was given by Scott et al. (1988) that there are local, resident stocks in certain embayments and that transient stocks migrate seasonally into and out of these embayments. In the Indian-Banana River, 28 of 36 marked bottlenose dolphins either resided in or returned to the river system for a period of at least ten years (Odell and Asper 1990). Eight of the marked dolphins were never positively resighted. None of the marked dolphins were reported from outside the river system; however, search outside of the river system was limited. If the working hypothesis is correct, exchange between resident and

1 NOAA, NMFS, Southeast Fisheries Science Center Contribution MIA-94/95-22.

transient components of the coastal stock could be sufficient to mask any genetic indicators of stock distinction, even though the stock components might be sufficiently distinct to respond differently to population pressures.

This stock, described as the coastal Atlantic migratory bottlenose dolphin stock, was listed as depleted under the Marine Mammal Protection Act after the occurrence of an unusually high level of mortality occurred in 1987-88, during which 780 bottlenose dolphin carcasses were recovered from beaches along the U.S. Atlantic coast. Using historical stranding rate data, Scott et al. (1988) estimated that approximately one-half of the population was affected by this event. This estimate was based upon assumed normal mortality rates and not upon population size estimates.

During July-August 1994, the Southeast Fisheries Science Center conducted a series of aerial surveys within approximately one km of shore along the U.S. Atlantic coast, from Long Island, New York, to mid-Florida to estimate bottlenose dolphin abundance. Another survey was conducted from the shore outward over the inner continental shelf in the area north of Cape Hatteras to obtain a line transect estimate of bottlenose dolphin abundance in this larger area. These data will be used to estimate the amount of survey effort required to obtain an abundance estimate with sufficient precision for monitoring trends in the population.

METHODS

Data Collection

Two NOAA DeHavilland DH-6 Twin Otter aircraft were used to conduct aerial surveys along shore from Long Island, New York, to Vero Beach, Florida, from July 12 - August 14, 1994. Both survey platforms were equipped with concave windows which allowed downward visibility for monitoring of the track line by an observer on each side of the aircraft. Surveys were flown at an altitude of 229 m and an airspeed of approximately 200 km/hr. Observers visually monitored the water surface from beneath the aircraft out to approximately one-half km from the track line. Bottlenose dolphin herd sightings and the sighting declination angle, measured with a hand-held digital inclinometer, were recorded into an onboard computer. When it was not possible to measure the declination angle, the angle was estimated using taped 10^0 markings on the observation window. Sightings of other cetaceans, marine turtles, individual large fish, fish schools, and debris were also recorded and factors which could affect sightability, such as weather, solar, and sea conditions, were noted. The location of the aircraft was automatically recorded into the computer directly from the aircraft geographical positioning system (GPS) at one minute intervals and when a sighting or change in survey conditions was recorded.

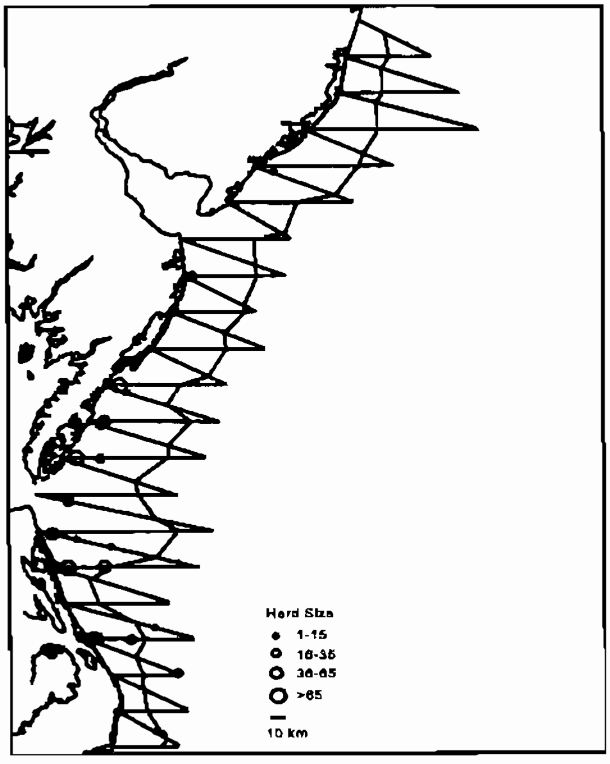

Figure 1. *Chart depicting transect lines and bottlenose dolphin herd sightings during line transect survey of mid-Atlantic bight. Transects extended to the 37 m isobath, but were truncated at the 25 m isobath, depicted here by the solid line intersecting the transects. Dolphin sightings beyond the 25 m isobath were not used in analysis.*

The surveys originated at Cape Hatteras, North Carolina. The two aircraft departed in separate directions from there, one counting bottlenose dolphins encountered along the shore from Cape Hatteras south, and the other counting bottlenose dolphins encountered along the shore from Cape Hatteras north. Each alongshore survey was conducted three times in order to obtain an estimate of the mean count and variance. An additional survey was conducted approximately 2.7-3.7 km from shore in the southern area for comparison with the alongshore counts.

In addition to these surveys, a line transect survey was conducted in the northern portion of the study area using transects flown across depth strata, thus across probable bottlenose dolphin density gradients (Figure 1). Line transect analysis (Buckland et al. 1993) was used to estimate bottlenose dolphin density throughout the area thought to be occupied by the coastal migratory stock under the assumption that bottlenose dolphin distribution was random with respect to the distribution of survey effort. Transects were flown at an altitude of 229 m in a zig-zag pattern from the shore out to the 37 m (20 fm) isobath. Transects were parallel to lines of latitude at 15' latitudinal intervals from 35^0 15' N to 40^0 15' N and connected using a diagonal transit.

All major bays and sounds north of Cape Hatteras were surveyed at least once using line transect methods with approximately 5% areal coverage. Three additional line transect surveys were conducted in the sounds and waterways in Port Royal Sound, South Carolina to replicate surveys conducted in that area in 1982, and provide comparative bottlenose dolphin abundance estimates. Analysis of line transect data from bays and sounds, including the Chesapeake Bay and the Port Royal Sound area, will be completed at a later date.

Data Analysis

<u>Direct Count Data</u>

Each survey was conducted over several days and the counts pooled to obtain a total count for each one-way transit. Data collected during each survey in the northern and southern sections were summed across the entire survey area for each one-way transit.

The sampling variance of the mean of the three counts was used to estimate the number of direct count surveys needed to achieve a coefficient of variation (cv) of 0.20 using the following equation (from Burnham et al. 1980, pg.35):

$$L = \frac{b}{(cv\hat{D})^2} \cdot \frac{L_1}{n_1} \tag{1}$$

where:

- $cv\hat{D}$ is the desired coefficient of variation of the density estimate;
- L_1 = the survey length;
- n_1 = the number of sightings; and
- $b = n_1(cv\hat{D}_1)^2$, where
- $cv\hat{D}_1$ = the observed coefficient of variation of the density estimate.

For this analysis, I have substituted N_1 (the number of surveys = 3) for L_1 in order to solve the equation for N, the number of like surveys which would be needed to achieve a cv = 0.20. This can be justified by the fact that the length of each survey was the same. The mean survey count ($\bar{C}$) was substituted for dolphin density ($\hat{D}$) and since $b = n_1(cv\hat{D}_1)^2$, the n_1 terms cancel and the equation becomes:

$$N = \frac{(cv\bar{C}_1)^2}{(cv\bar{C})^2} \cdot N_1. \tag{2}$$

Line Transect Survey Data
The computer program DISTANCE (Laake et al. 1993) was used to analyze the line transect survey data using distance sampling analysis methods (Buckland et al. 1993) to estimate dolphin density and extrapolate the estimate of dolphin density to abundance. In order to reduce the possibility of including the offshore bottlenose dolphin stock in the abundance estimate, survey data were post-stratified by excluding effort and sighting data seaward of the 25 m isobath. There is no assurance, however, that dolphins from the offshore stock were completely excluded in the sighting data.

Herd sightings were grouped into intervals corresponding to 10^0 declination angles to model the probability density function (PDF) and estimate $\hat{f}(0)$. The uniform distribution function, the half-normal model, and the hazard-rate model were evaluated and the model providing the best fit was chosen using Akaike's Information Criterion (AIC, Akaike 1973). AIC incorporates the log-likelihood function and the number of model parameters for each candidate model to identify a model which fits the data well with the fewest parameters (Buckland et al. 1993).

The observed mean herd size for each stratum was evaluated for bias with respect to PSD using linear regression of the log-transformed herd size against g(x) of the PDF model. The expected herd size calculated using the model was used to estimate dolphin density if the regression equation was significant at $P \leq 0.15$, otherwise the observed mean herd size was used.

Bottlenose dolphin sightings were stratified by herd size in the analysis in order to examine the effects of herd size on the density estimate and bottlenose dolphin abundance was estimated as the weighted sum of the stratum abundance estimates. The data were also analyzed without stratification for comparison.

Each transect was treated as a replicate unit of sampling effort and dolphin density was estimated as:

$$\hat{D}_i = \frac{n\hat{f}(0)\hat{E}(S)}{2l_i} \tag{3}$$

where:

$I = 1..k$, for k transects;
n_i = the number of bottlenose dolphin herd sightings on transect I;
l_i = the length of transect I; and
$\hat{E}$ = expected herd size;

from Buckland et al. (1993, pg. 91). Dolphin density was calculated using the line length-weighted density estimates (Buckland et al. 1993, pg. 92, Eq. 3.14):

$$\hat{D} = \frac{[\sum_{i=1}^{k} l_i \hat{D}_i]}{l} \tag{4}$$

with total line length L. Dolphin abundance is the product of bottlenose dolphin density and the survey area which was measured approximately from the appropriate NOAA-NOS charts. For the herd size-stratified analysis total abundance is the sum of the abundance estimates for each of the four herd size strata and its variance is the sum of the within-stratum analytical variance.

RESULTS

Direct Count Surveys

The northern survey area, from Sandy Hook, New Jersey, to Cape Hatteras, North Carolina, included approximately 620 linear km and the southern survey area, between Cape Hatteras and Ft. Pierce, Florida, totaled approximately 1,100 linear km, thus the entire direct count survey area covered approximately 1,720 km. The southern coast of Long Island (approximately 180 km) was completely surveyed once and partially surveyed twice, but dolphins were never sighted there. Results of the survey counts between Sandy Hook and Ft. Pierce are given in Table I.

The survey coefficient of variation in the northern survey area was 0.744. Using Equation (2), I calculated that 42 surveys of the area between Sandy Hook and Cape Hatteras would be required to achieve a coefficient of variation of 0.20 with a nearshore survey of the coastal migratory bottlenose dolphin stock.

One additional survey was conducted in the southern survey area approximately 2-3 km away from shore on the day following survey number 3. The results of this survey are not shown in Table I, but 752 bottlenose dolphins were counted (versus 815 seen within one km of shore on the previous day). These dolphins probably would not have been detected from a transect placed one-half km from shore. For comparison, the average number of bottlenose dolphins counted in the nearshore survey of the southern coastal area was 630 dolphins (Table I). The herd sighting rate for the offshore survey in the southern area was 0.055 herds/km which was comparable to the mean herd sighting rate for the nearshore area (0.062 herds/km, cv = 0.16, Table I).

Table I. *Results of the alongshore bottlenose dolphin surveys. C is the number of bottlenose dolphins counted, R is herd sighting rate (herds/km), S is mean herd size, SD is standard deviation, and cv is coefficient of variation.*

Survey	South			North			Total
Number	C	R	S	C	R	S	C
1	577	0.064	8.2	303	0.066	16.0	880
2	497	0.071	6.4	810	0.074	17.6	1,307
3	815	0.052	14.3	1,667	0.084	32.1	2,482
Mean	630	0.062	9.6	927	0.075	21.9	1,556
SD	165	0.010	4.1	689	0.009	8.8	830
cv	0.26	0.16	0.43	0.74	0.12	0.40	0.53

Line Transect Survey

The line transect survey between Sandy Hook and Cape Hatteras out to the 25 m isobath included approximately 1,666 linear km of on-transect effort (Figure 1). Thirty one bottlenose dolphin herds were sighted resulting in a herd sighting rate of 0.0186 herds/km (cv = 0.24). Most herds contained $\leq$ 65 dolphins, but three herds were $\geq$ 100 dolphins in size (Figure 2). There were four obvious groupings of herd sizes: 1-15 dolphins; 16-35 dolphins; 36-65 dolphins, and herds containing > 65 dolphins. These four ranges were used to stratify the data for estimating abundance using line transect analyses.

A half-normal model with two cosine adjustment terms provided the best fit to the PSD distribution based on the AIC (Akaike 1973) ($\chi^2 = 3.116$, df = 4, P = 0.539) (Figure 3). This resulted in $f(0) = 3.863$ (cv = 0.20) or an effective strip width of 0.517 km. Bias towards sighting larger herds at greater distances was not evident in the herd size strata of 1-15, 36-65, or > 65 dolphins/herd. Herd size bias was significant in the 16-35 dolphins/herd stratum (Table II); therefore, the model-based expected mean herd size was used in calculating dolphin density in this stratum. The point abundance estimate using the herd size stratified analysis was 25,841 bottlenose dolphins with a 95% confidence interval (ci) = 13,010-51,329, assuming a log-normal distribution.

Visual coverage of the approximate 25,659 km^2 survey area was approximately 861 km^2; thus, approximately 3.3% of the total survey surface area was visually searched for dolphins. The coefficient of variation for the abundance estimate was 0.40. Mean herd size contributed 39% to the estimated variance of the abundance estimate and herd encounter rate contributed 36%. The smallest contributor to overall error was the detection probability at 25%. Given the cv of 0.40 for this survey and using Equation (2) to solve for L, approximately 6,664 km of survey transect would be necessary to achieve a cv of 0.20, assuming no improvement in the variance of $f(0)$.

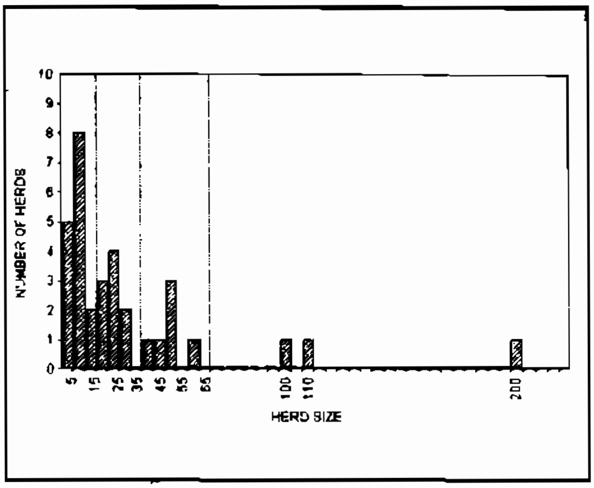

Figure 2. *Distribution of bottlenose dolphin herd sizes recorded during line transect surveys from Sandy Hook, New Jersey, to Cape Hatteras, North Carolina, out to the 37 m isobath. Vertical lines indicate herd size strata used in line transect analysis.*

DISCUSSION

The bottlenose dolphin found close to shore is believed to be morphologically and hematologically distinct from the larger, more robust bottlenose dolphin found offshore in U.S. Atlantic waters. Hersh and Duffield (1990) referred to the two types as a shallow, warm water ecotype and a deep water ecotype. The distribution of bottlenose dolphin sightings during surveys conducted by the Cetacean and Turtle Assessment Program in 1979-1980 (CeTAP 1982) suggested that there was a disjunct distribution of bottlenose dolphin sightings with the center of the separation at the 25 m isobath (Kenney 1990). This separation may delineate the normal bathymetric ranges of the two ecotypes in the area north of Cape Hatteras; however, there was no apparent longitudinal separation of bottlenose dolphin sightings during aerial surveys south of Cape Hatteras during winter surveys (Blaylock and Hoggard 1994).

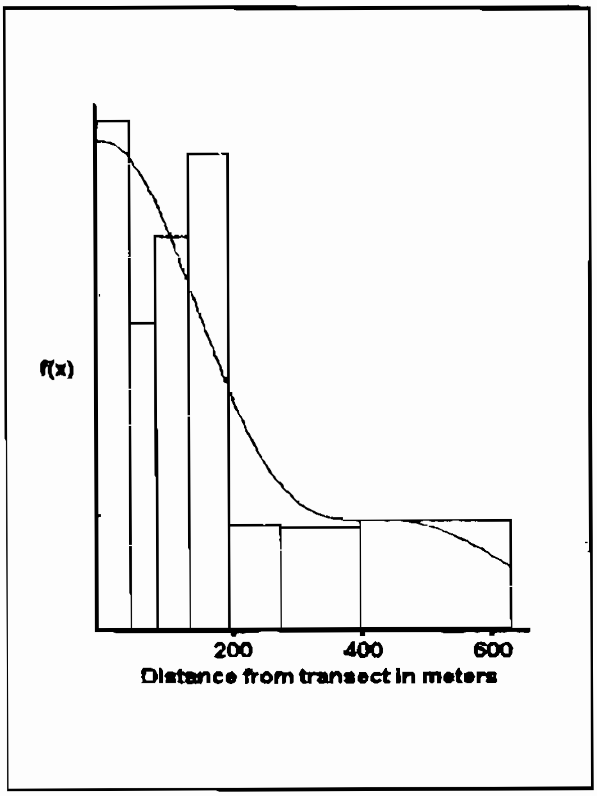

Figure 3. *Half-normal probability density function (curve) fit to histogram of perpendicular sighting distances.*

Table II. *Line transect estimates of bottlenose dolphin herd density and dolphin abundance. N is the number of herds sighted in the stratum range,* $\bar{S}$ *is the observed mean herd size,* $\hat{S}$ *is the estimated mean herd size adjusted for size-sighting distance bias, cv is coefficient of variation, P is the probability of a greater Student's t-value,* $\hat{D}$ *is bottlenose dolphin herd density (herds/km²), and* $\hat{A}$ *is bottlenose dolphin abundance. The mean herd size estimate used for calculating bottlenose dolphin density is shown in bold type. "Total" is the sum of the stratum estimates and cv*$\hat{D}$ *was estimated from the sum of the stratum variances. The PDF model and* $\hat{f}(0)$ *were the same for both analyses.*

Herd size	N	$\bar{S}$	cv $\bar{S}$	$\hat{S}$	cv $\hat{S}$	P	$\hat{D}$	cv$\hat{D}$	$\hat{A}$	cv$\hat{A}$
1-15	15	**7.6**	0.13	7.4	0.22	0.43	0.0174	0.37	3,386	0.39
16-35	9	21.6	0.04	**18.1**	0.09	0.02	0.0104	0.45	4,839	0.46
36-65	4	**45.8**	0.06	42.6	0.13	0.29	0.0046	0.52	5,436	0.52
> 65	3	**136.7**	0.23	150.4	0.34	0.64	0.0035	0.54	12,179	0.59
Total	31	—	—	—	—	—	0.0090	0.29	25,841	0.36
Not stratified	31	**29.1**	0.25	42.1	0.29	0.90	0.0359	0.33	26,809	0.40

Direct Count Surveys

The abundance estimate resulting from the direct count is negatively biased and must be considered a minimum abundance estimate for two reasons. The violation of the fundamental sampling assumption of random distribution by placement of the longshore transect parallel to shore, thus along the gradient of bottlenose dolphin density, precluded the extrapolation of a density estimate to estimate abundance over the stock range. Furthermore, it was assumed that all bottlenose dolphins which were at the water's surface when the aircraft passed overhead were detected. Failure of this assumption would result in a negative bias of the abundance estimate. Observers on shore later reported that the survey aircraft failed to circle at a location where the onshore observers sighted dolphins immediately before and after the survey aircraft passed (K. Spencer, personal communication, August 1984). This suggests that those dolphins were not sighted by the survey team.

The low number of surveys undoubtedly contributed to the high variance for the resulting average count. Forty-two surveys would be required to achieve a cv of 0.20 and, thus judged useful for monitoring population trends (a halving or doubling of the estimated population size with a probability of Type II error of $\leq$ 20%) in the coastal migratory bottlenose dolphin stock. Approximately 70 flight hours were required to complete the three surveys in the pilot study of the northern area, thus approximately 980 flight hours would be needed to achieve a coefficient of variation approaching 0.20.

The results of the nearshore direct count surveys suggest that this is a suboptimal method for estimating bottlenose dolphin abundance in the coastal area. The large variance associated with the alongshore survey implies that the distribution of the coastal bottlenose dolphin stock may be highly variable. This could result from coastal dolphins following prey which were moving in response to changing nearshore environmental conditions. The distribution of coastal dolphins south of Cape Hatteras may have also been influenced by the distribution of shrimp boats. The number of bottlenose dolphins which were found three km distant from shore in the area between Savannah, Georgia, and Vero Beach, Florida, was comparable to the number counted in the nearshore survey along the same portion of coast on the previous day and many of those three km from shore were closely associated with working shrimp boats. It is also possible that some, or all, of those dolphins sighted three km from shore were the deep water ecotype; however, the distribution of the deep water ecotype south of Cape Hatteras has not been described.

Line Transect Surveys

The line transect survey produced a more precise estimate of abundance than did the direct count surveys. Approximately 30 flight hours were required to conduct the pilot line transect survey with a cv of 0.40, using the non-stratified design. Based upon these data, approximately 120 survey flight hours using line transect methods should produce a cv of 0.20 in the northern survey area. This suggests that the standard line transect survey design is the relatively more efficient method for monitoring this stock.

The line transect survey may provide a less biased dolphin abundance estimate than the direct count within one km of shore because it samples across all potential habitat, although the abundance estimate may still be negatively biased because the proportion of dolphins submerged when the survey aircraft passes overhead is unknown. The numerous bottlenose dolphin herd sightings at distances greater than one km from shore during the line transect surveys north of Cape Hatteras indicate that there were a substantial number of bottlenose dolphins in the region which were outside of the area surveyed during alongshore direct count surveys; however, it is unknown what proportion of those animals might have been of the deep water ecotype.

The lower 95% confidence limit (95% cl) of 13,010 bottlenose dolphins was similar to Mitchell's pre-exploitation estimate of 13,748 bottlenose dolphins (Mitchell 1975) which were the focus of a fishery at Cape Hatteras, North Carolina during the late 1880's and into the early 1900's. Because the fishery operated from shore and peaks of catches occurred in the spring and fall, corresponding with the seasonality of bottlenose dolphin migration through this area, this fishery may have targeted the migratory portion of the coastal stock.

A mean bottlenose dolphin abundance of 12,435 (95% ci = 9,684-15,967) was estimated from aerial surveys conducted in the coastal U.S. waters south of Cape Hatteras during the winter in 1992 (Blaylock and Hoggard 1994). This estimate is also similar to Mitchell's (1975) pre-exploitation estimate and compares favorably to the lower 95% cl of the current line transect estimate.

If the three sightings of herds containing > 65 dolphins (9.1% of the total sightings) are excluded from the analysis of the line transect surveys reported here, the resulting average abundance estimate is 13,661 bottlenose dolphins (95% ci = 9,237-20,203). This number compares favorably with both Mitchell's pre-exploitation estimate and the 1992 winter survey results. It is assumed that the coastal stock predominated in Mitchell's estimate; however, given the problem of distinguishing the two stocks during aerial surveys, it is not certain that the offshore stock was entirely excluded in the line transect surveys. The distribution patterns of the two stocks will require much more study to solve this problem.

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